

APPENDIX 1

Public and Peer Review Panel Comments

Appendix 1-2 Comments from the Public and Consultants

Appendix 1-2c Comments from Tetra Tech, Inc.

A1-2c	Tetra Tech, Inc.'s Introduction to Comments on Behalf of Sugar Cane Growers Cooperative of Florida.....Page A1-2c-1
A1-2c	"An Overview of the Historical Everglades Ecosystem and Implications for Establishing Restoration Goals".....Page A1-2c-Page 1

The submission to the 2001 Everglades Consolidated Report is included in this appendix in deference to the efforts made by the Cooperative. The report was presented as a publication to be considered as a form of peer review. Although unique in its format for this appendix, the District feels the report is of such interest that its inclusion is useful and appropriate.

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Topic: Historical nutrient gradient presentation (1 of 2), Read 60 times

Conf: [Everglades Report - Peer Review](#)

From: Sujoy Roy sujoy@tetrattech.com

Date: Friday, October 13, 2000 03:29 PM

We would like to thank the South Florida Water Management District and the peer-review panel for giving us an opportunity to present our thoughts on the existence of a historical nutrient gradient in the Everglades.

Evidence for this gradient is based on the likelihood of elevated phosphorus concentrations in the waters of Lake Okeechobee and the hydrologic connection between the lake and the Everglades. The existence of thick peat deposits nearest the lake is very likely related to the nutrient supply. Modern and historic accretion data from WCA-2A (Craft and Richardson, 1998) provides a basis for this statement.

When data from enriched areas of WCA-2A are considered, nutrient enrichment results in a significant increase in the peat accretion rate. For example, accretion rates in recent years based on cesium dating were 5.8 and 7.6 mm/year in two enriched sites in WCA-2A, and 2.7 mm/yr in an unenriched site in WCA-2A. Longer term accretion rates at the same locations, reflective of pre-enrichment conditions, measured with lead-210, show that the accretion rates were very similar at all three sites (1.7 to 2.1 mm/yr). (Data from Craft and Richardson, 1998.) We think the nutrient supply from the lake, over centuries, caused a similar buildup of thicker peat deposits in areas near the lake. Hydrology also played a role in distributing the carbon in the landscape, but the greater productivity in the area south of the lake was an essential first step.

For your reference, an electronic copy of our presentation marked up with references and notes is attached to this message as a pdf file.

Sincerely,

Sujoy B. Roy and Steven Gherini
Tetra Tech, Inc.
Lafayette, CA 94549

Reference: Craft, C.B. and C. J. Richardson (1998). Recent and long-term soil accretion and nutrient accumulation in the Everglades, Soil Science Society of America Journal, Vol. 62, pp. 834-843.

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Topic: Historical nutrient gradient presentation (2 of 2), Read 73 times

Conf: [Everglades Report - Peer Review](#)

From: [Sujoy Roy](#) sujoy@tetrattech.com

Date: Friday, October 13, 2000 03:35 PM

I could not attach the presentation file to the message (it may be a size issue). I will email this file to Dr. Garth Redfield and Dr. Jeff Jordan.

Thanks.

Sujoy B. Roy

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*Please note that the attached document referred to in this email is not included in this appendix. The document included is the full report that the mentioned document was a presentation of at the peer review workshop.

An Overview of the Historical Everglades Ecosystem and Implications for Establishing Restoration Goals

Prepared by:

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Submitted on behalf of the Sugar Cane Growers Cooperative of Florida, to
South Florida Water Management District
3301 Gun Club Road
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June 2000

AN OVERVIEW OF THE HISTORICAL EVERGLADES ECOSYSTEM AND IMPLICATIONS FOR ESTABLISHING RESTORATION GOALS

ABSTRACT

This report summarizes the processes that led to the formation of the Everglades over 5000 years. The information underlying this summary was obtained from a survey of historical reports, data from measurements of peat and sediment cores, and flow modeling using the South Florida Water Management District's Natural System Model. Available evidence shows that a natural phosphorus-enriched zone existed south of Lake Okeechobee that contained dense growths of pond apple and other upland species and an associated variety of birds and wildlife. Based on the bedrock profile and peat age, it is also believed that Lake Okeechobee covered a larger area, perhaps extending as far south as the current boundaries of Water Conservation Area 1. Because Lake Okeechobee was higher in nutrients than the areas south of it, this larger lake is believed to have had adjacent deposits that were enriched in phosphorus compared to areas of the Everglades farther south.

The historical existence and ecological value of the enriched zone are pertinent to the restoration plans for the Everglades. A habitat characterized by nutrient levels above those seen in the most oligotrophic portions of the Everglades should be an explicit part of any restoration plan. Such a zone will be established in the northern parts of Water Conservation Areas 2A and 3A, by the outflow from Stormwater Treatment Areas now nearing completion. Historical and current evidence indicate that this enriched zone, at current and planned inflows, will attain steady state rather than spread continually into the interior of the marsh. Additional phosphorus introduced to the area will be incorporated in greater depths of peat, and not an expanding front of higher soil and water concentrations. Use of the elevated nutrient zones to develop some of the habitats that have been lost, even though they were not historically found in these precise locations, will facilitate a restoration that has the potential for providing the heterogeneity of habitat that was so vital to the health of the historical Everglades.

INTRODUCTION

The Everglades ecosystem has been the focus of large-scale restoration efforts in recent years. The current extent of the Everglades ecosystem, including the canals and the water flow structures, is shown in schematic form in Figure 1. Water

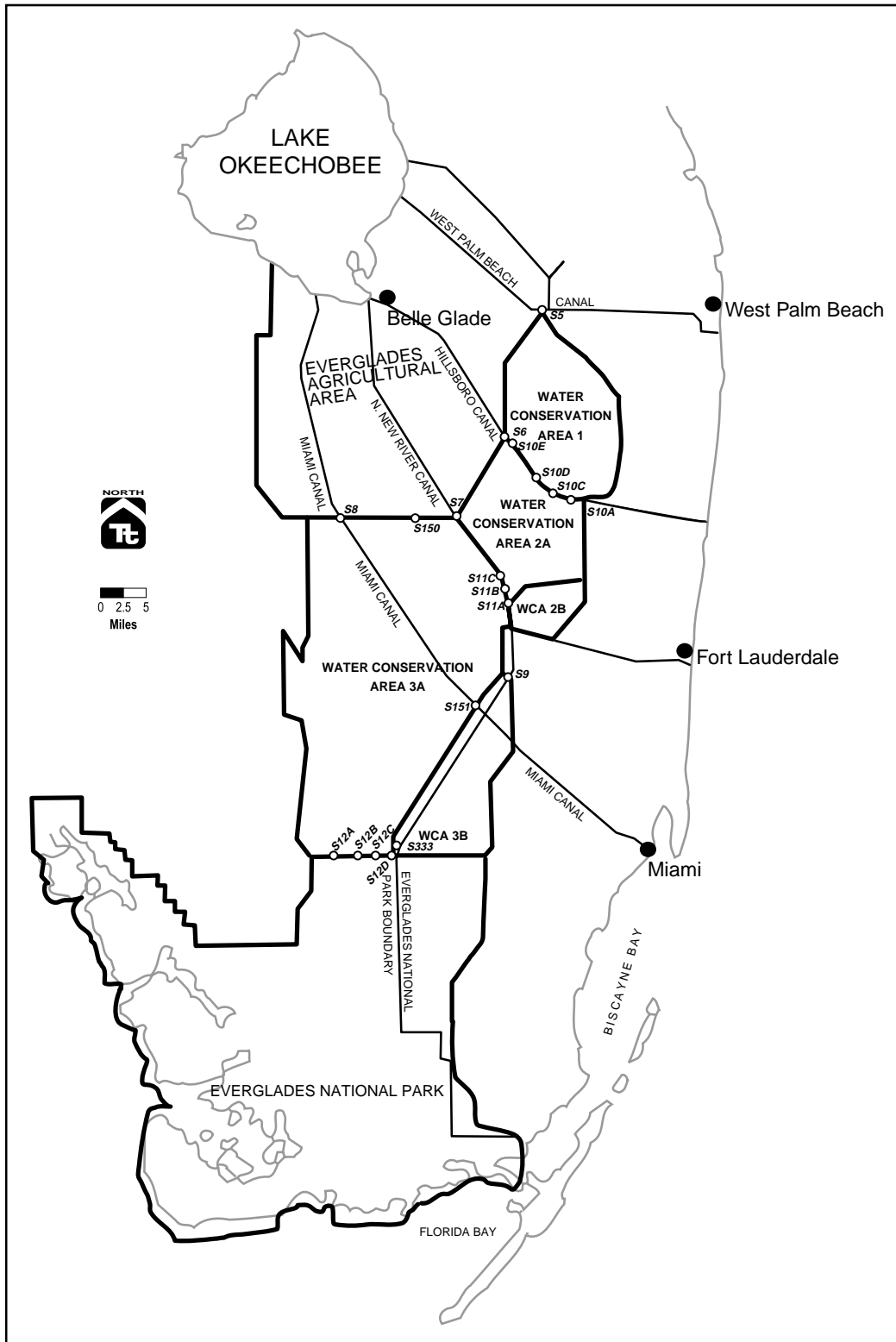


Figure 1. Schematic of the current Everglades region. The letter-number combinations identify the flow control structures in the system.

generally flows south and east from the Everglades Agricultural Area (EAA) and Lake Okeechobee, through the three Water Conservation Areas (WCAs) into the Everglades National Park and toward the Gulf of Mexico. Two independent restoration efforts are underway in the Everglades. The first, following the implementation of the Everglades Forever Act (EFA), plans for the development of Stormwater Treatment Areas (STAs) to treat water entering the WCAs, principally to reduce the amount of phosphorus entering the area, and also to establish sheet flow to portions of the northern Everglades. The second major effort, the Comprehensive Everglades Restoration Plan (CERP) seeks to restore natural water flow to the Everglades by replicating the quantity, timing, distribution and quality of flow of the “natural system.” This will be accomplished in part by removing selected levees and canals from the existing system and reducing the loss of groundwater through the eastern boundary of the remaining Everglades. The extent of human influence on this system, and the difficulty of restoring it to anything that resembled the natural state, can be appreciated by studying a recent USGS map of the region (Figure 2).

As part of the ongoing restoration efforts, a large amount of field research has focused on understanding the impacts of anthropogenically-derived nutrient enrichment in the Water Conservation Areas of the Everglades. The objective of that ongoing effort is to determine threshold nutrient concentrations below which no substantial biological changes can be found in the most oligotrophic areas of the Everglades. This approach fails to consider that portions of the historical Everglades were not an oligotrophic marsh. The ecosystem contained zones of higher productivity and greater wildlife abundance and diversity that were supported by elevated nutrient levels. Restoring the ecosystem to a uniform oligotrophic state would preclude these zones and provide only those habitats characterized by extremely low nutrient availability. The current restoration objectives do not explicitly account for the heterogeneity of the ecosystem that existed prior to drainage.

This paper presents evidence for the historical existence of a nutrient enriched vegetation zone in the Everglades that was spread over a larger area than is generally understood today, and shows that this region was sufficiently productive to allow the accretion of several feet of nutrient-rich peat over the past few millennia. This zone was a very important habitat for birds and wildlife. When developing the restoration plans for the Everglades, explicit consideration should be given to providing an area of higher nutrient availability along the upstream boundary of the remaining Everglades. Areas downstream of the STAs, now nearing completion, as

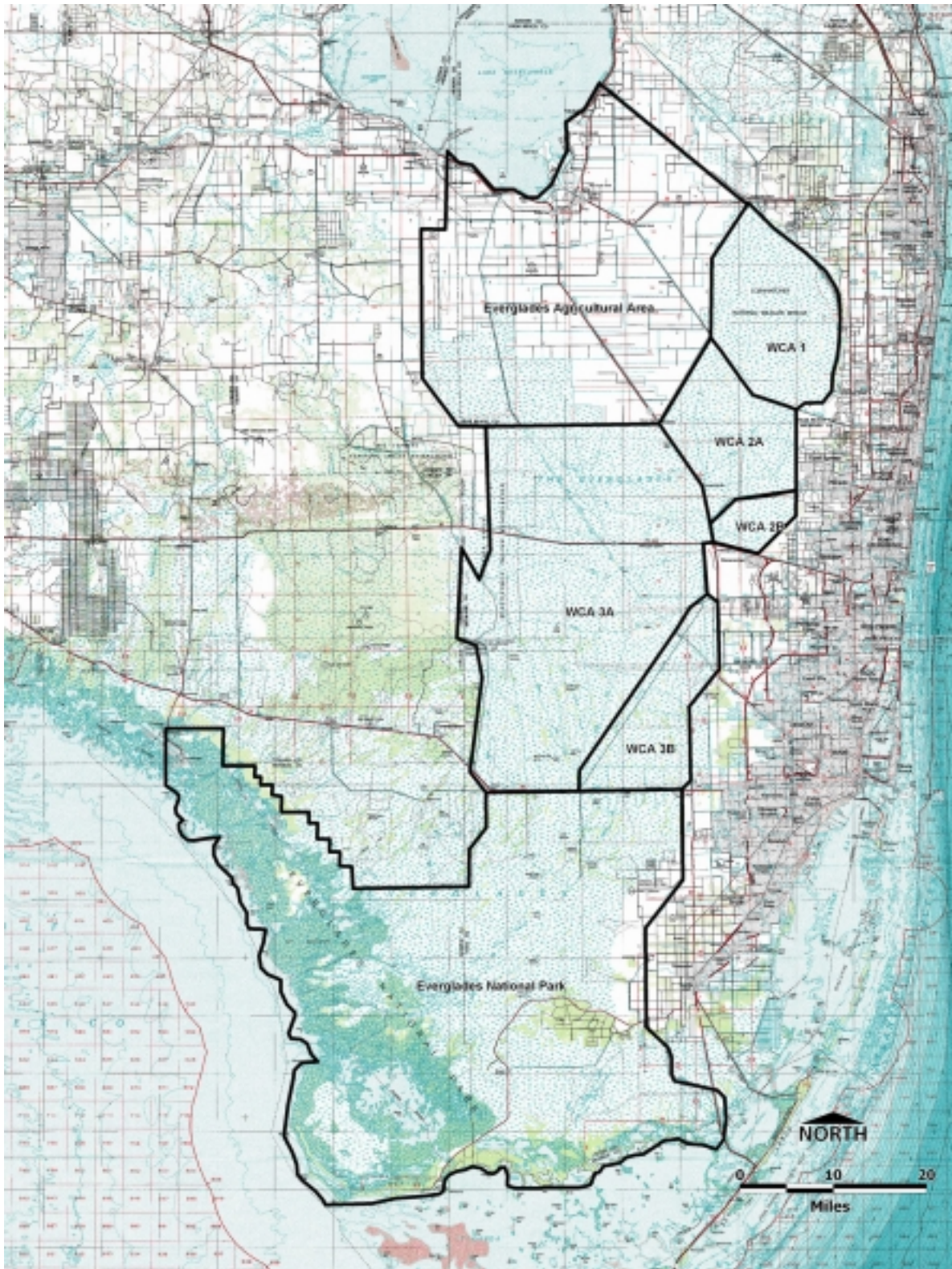


Figure 2. Detailed map of south Florida including the Everglades and surrounding areas.

well as existing areas with elevated nutrient concentrations, such as the northern portion of WCA-2A, should be able to meet the most important criteria for the establishment of these special centers of biological productivity and diversity.

Historically, the Everglades ecosystem included a wide range of nutrient availability with regions of high nutrient concentrations, along the southern rim of Lake Okeechobee, and in the tree islands, which were scattered in great abundance (Hammar, 1929; Davis, 1943) throughout a larger area of the Everglades. Tree islands are known to have higher nutrient concentrations than the surrounding marshes. These nutrient enriched regions were a vital part of the ecosystem, serving as home to birds and wildlife. The sawgrass marshes, although a large part of the Everglades, supported far less species richness. The primary issue that restoration planners have to address is described by McCally (1999):

“The form that the sustainable system will assume is the conceptual element of restoration. Currently the metaphor “river of grass” and the image of vast stands of saw grass that this metaphor suggests represent the historic Everglades in the minds of most Americans. This image must be replaced. The sustainable system must include forests, tree islands, and mangrove swamps that characterized the predrainage South Florida, and resurrection of the image of islands and seas, formulated before drainage altered the Everglades, would contribute greatly to the establishment of a sustainable system.”

We present a summary of historical ecological conditions in the Everglades so that these different components can be explicitly considered in planning for the restoration of this unique ecosystem. In the description that follows, our particular emphasis will be on the northern Everglades, which is now composed of Water Conservation Areas 1, 2, and 3, and on the Everglades Agricultural Area. An overview is presented of the formation and history of these parts of the historical Everglades landscape based on recent scientific measurements and historical descriptions of the ecosystem. The discussion below is divided into two parts. Key components of the historical ecosystem are first presented, followed by the implications of these findings on the restoration targets for the ecosystem.

1. OVERVIEW OF THE ECOSYSTEM

The Everglades formed as peat deposits over limestone over the past 5000 years. Because this is a very young system, geologically speaking, an improved understanding of how the topography and vegetation of the region developed over this time can provide insight into how its ecosystem was established. The topography

influenced the flow of water southward over this terrain, and because the water is likely to have been higher in phosphorus in the northern regions of the system, the topography influenced where the additional phosphorus was transported in the system. The nutrients in turn influenced the quantity and type of aquatic vegetation that grew in the region, and led to the accretion of peat at different rates. The peat deposits in turn modified the topography and thus the flow of water and delivery of nutrients. The dynamics of this ecosystem, and the interactions of biota and water flow, are critical to understanding the characteristics of this region before man-made drainage systems initiated other large-scale changes. An appreciation of the dynamics of the system is also essential in developing restoration plans for the Everglades.

Topography and Hydrology

The Everglades was a relatively flat landscape prior to drainage, with a drop in elevation from 20 feet above sea level near the south shore of Lake Okeechobee to sea level over a distance of 100 miles (Figure 3). However, the limestone that lies beneath the peat deposits is less uniform, and shows more topographic highs and lows (Figure 4, based on a digitized USGS map from 1955). This underlying surface played a more significant role in controlling the flow of water during the formative centuries of the Everglades. For example, the bedrock in the region from the southeastern edge of Lake Okeechobee to the current boundaries of WCA-1 is lower in elevation and formed what is referred to as the Loxahatchee Channel (Gleason et al., 1974). It is likely that this depression formed an eastern extension of Lake Okeechobee, which behaved more like a lake than a marsh. Water therefore did not flow directly south of the current boundaries of Lake Okeechobee, but rather east and then south into WCA-1, and ultimately to what is now the Everglades National Park. Over time, peat deposits filled the Loxahatchee channel and the preferred pathway for water flow became directly southward from the lake.

Apart from the limestone surface, there is another line of investigation that supports the existence of an eastern extension of Lake Okeechobee. Radiocarbon dating of peat in Belle Glade was first performed by McDowell et al. (1969) and the age of the deepest layers of peat was found to be approximately 4,300 years. Gleason et al. (1974) performed additional radiocarbon dating of peat cores from the northern and southern part of WCA-2A and from WCA-1 (reproduced in Figure 5). The results of this dating showed that the basal peat in the northern part of WCA-2A is as old as that collected from near the south shore of Lake Okeechobee (approximately 4,200-4,900 years). How did the basal peat over a 20 mile zone stretching from the south of Lake Okeechobee to the north of WCA-2A form at roughly the same time? If sheet

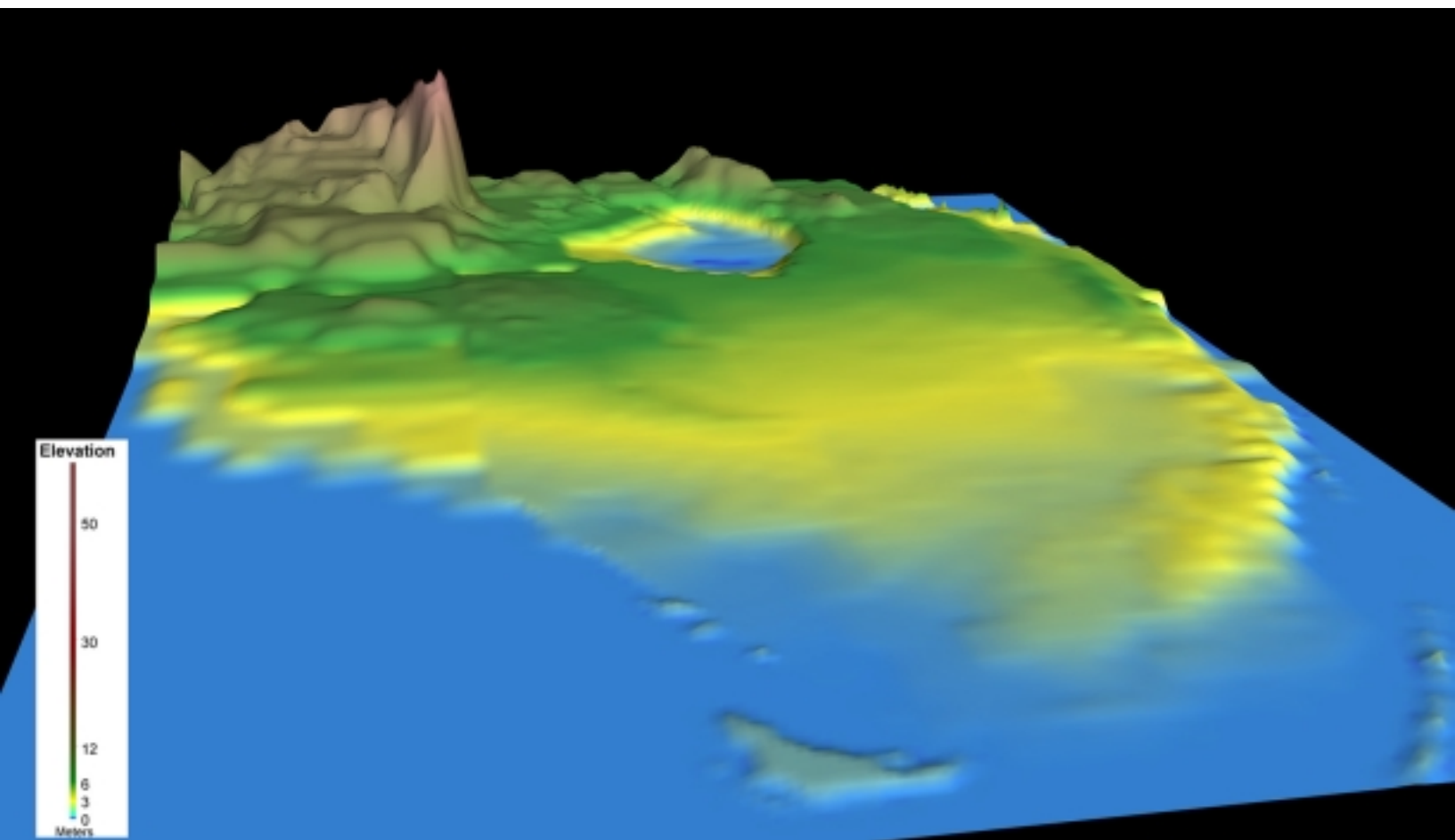


Figure 3. Elevation map of the Everglades used for input to the Natural Simulation Model. These elevations were reconstructed from historical accounts and are intended to represent conditions prior to large-scale drainage of the Everglades (~1850). The vertical scale is exaggerated.

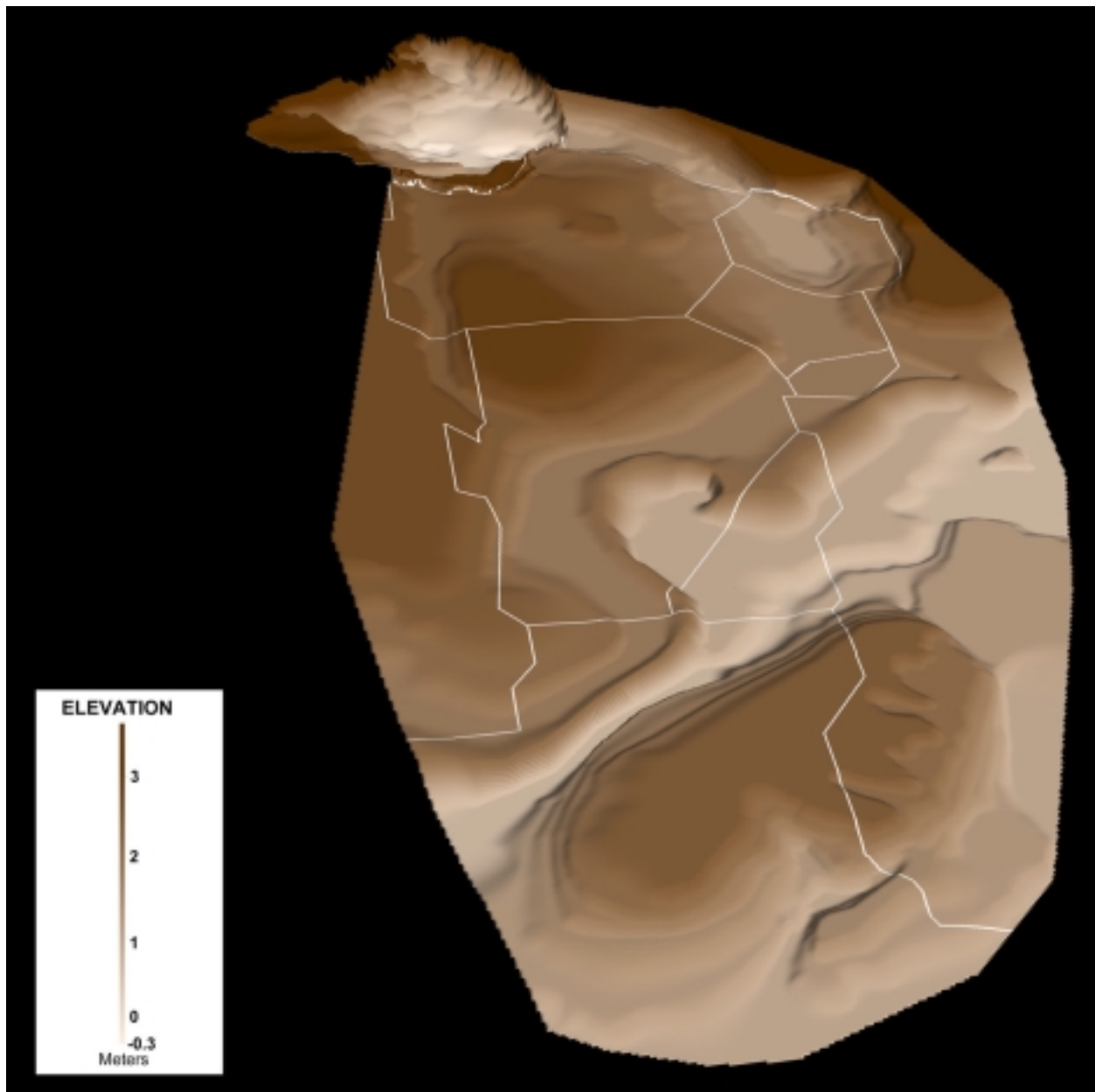


Figure 4. Elevations of limestone bedrock surface underlying the peat in the Everglades. Data for this map were digitized from Parker (1955). The vertical scale is exaggerated. The white lines delineate the boundaries of the EAA, the WCAs, and the Everglades National Park (see Figure 1).

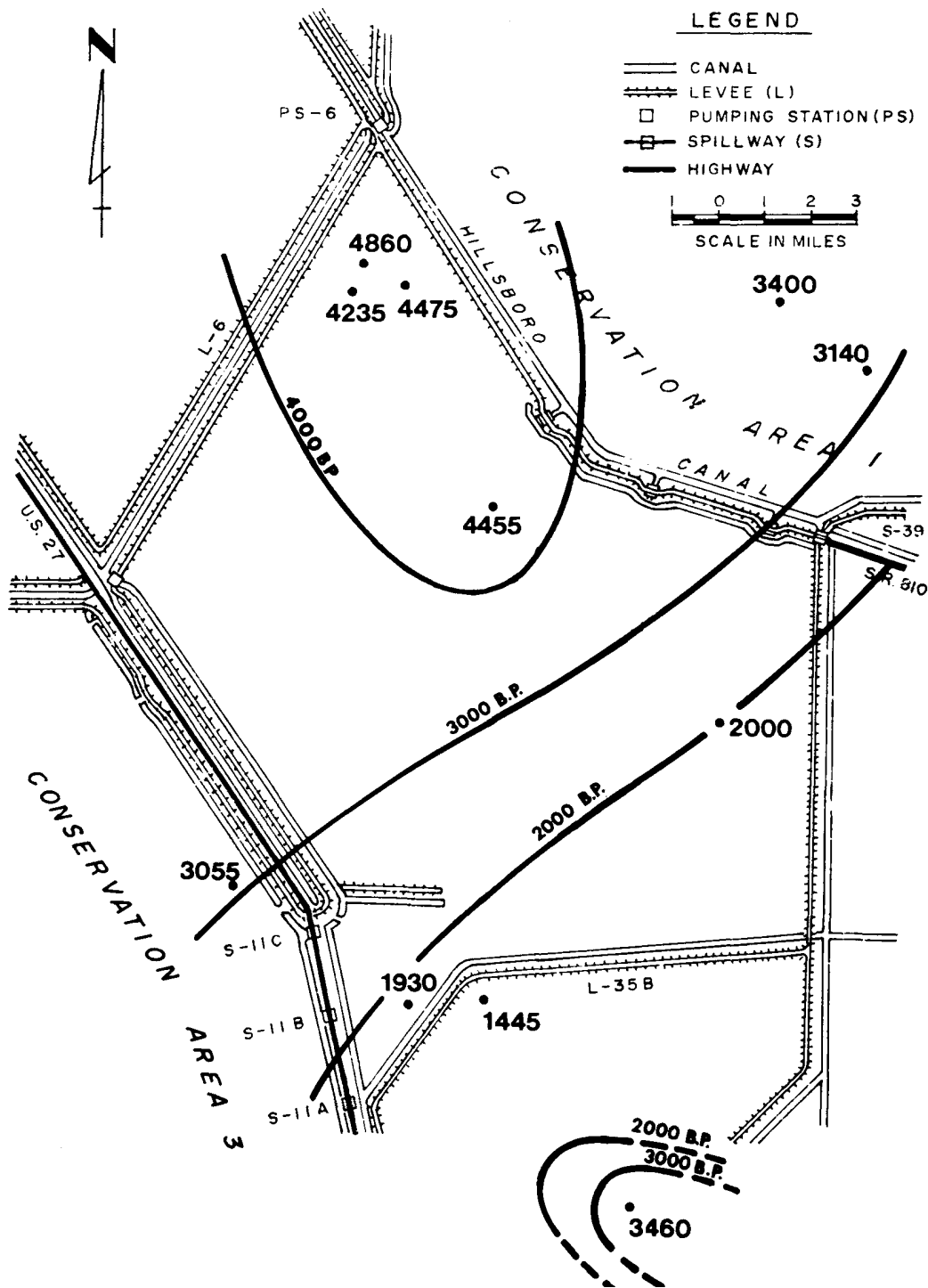


Figure 5. Age of basal peat in different parts of WCA-2A, as measured and reported by Gleason et al., 1974. Figure reproduced from Gleason et al., 1974.

flow had occurred over the area from north to south historically, the basal peat near WCA-2A would be much younger than the data show it is. This is because the zones nearest the source of nutrients (the lake) would have formed peat deposits first, with overflows gradually forming deposits further away. Thus, the age of the basal peat provides an indication of the historical proximity to a nutrient source, with older peats being found near the nutrient source. The basal peats in the southern part of WCA-2A (Figure 5) and the Everglades National Park (Craft and Richardson, 1998) are much younger (~2,000-2,500 years) because they were further away from a nutrient source. The likely reason that peat deposits near the south shore of Lake Okeechobee and the north part of WCA-2A are the same age, and among the oldest in the region, is that at some time in their past, they were both near the edge of a lake that served as a nutrient source. This historical lake included all of the current boundaries of Lake Okeechobee and a limb that stretched south into WCA-1.

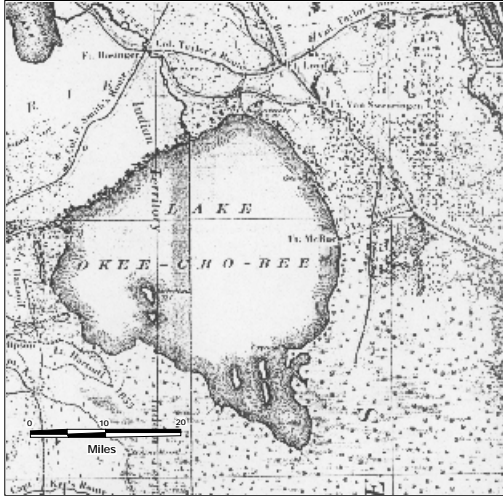
By the time mid-19th century western explorers encountered the Everglades, the Loxahatchee channel had become a marsh, and flow in the system was predominantly north to south. Water moved south from the lake through several rivers that were as much as forty to eighty yards wide. These rivers eventually blended with the marsh a few miles from the edge of Lake Okeechobee (Small, 1918).

As described in surveys from the late 19th and early 20th centuries, historical lake elevations were considerably higher than they are today. Reports by Harney (1884) and Clark (1907) indicate that the lake was generally over 20 feet above sea level. The Natural System Model (NSM), which estimates pre-drainage flow conditions, also calculates approximately this value for the lake surface elevation. In addition to the greater depth of the lake, older maps show that the lake boundaries were different than shown in maps from the 20th century (Figure 6, and similar estimates by SFWMD, 1999). It is logical to assume that the surface area of the lake decreased as its water level was lowered over the past 120 years, although historical lake maps are less accurate and historical lake boundary locations are a bit uncertain over this short time period. In addition, as shown in the next section, it is very likely that over time periods of several centuries, the lake boundaries significantly changed.

Hindcasts of Hydrology Based on the Natural System Model

A numerical model of the pre-development hydrology of the Everglades system, the NSM, was used to develop a semi-quantitative understanding of the dynamics of the hydrology of the region over the last 4000 years. The NSM has been developed and used by the South Florida Water Management District (SFWMD) to understand the regional hydrology prior to the initiation of

1856



1857



1860



Modern Boundary

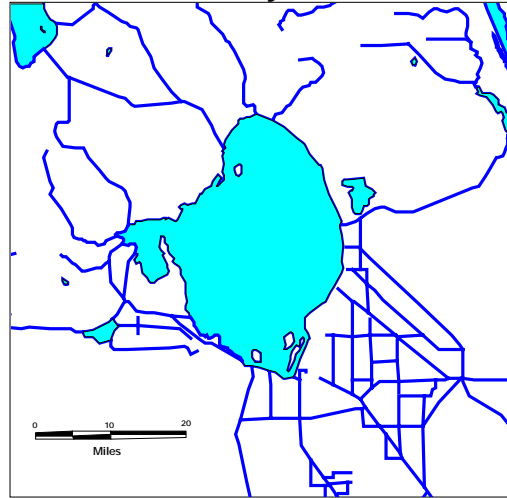


Figure 6. Boundaries of Lake Okeechobee from three historical maps from the 19th century. These boundaries are compared with the modern boundaries of the lake. All four maps are drawn at the same scale. The historical maps were obtained from the Florida State Archives.

drainage using topography that represents conditions as they might have been in 1850. We used the NSM with a variation of this concept: topography from 1,000, 2,000, 3,000, and 4,000 years prior to drainage was input into the model, and the resulting simulations were used to study how the water flows and depths might have changed over time. This is important because the quality and quantity of water define the vegetation communities and associated fauna that may have been present.

Data used to perform historical reconstruction of peat formation were obtained from radio-carbon dating of peat cores collected from Belle Glade in the EAA (McDowell et al., 1969). The normalized peat thickness at this location as a function of time is shown in Figure 7, based on data from triplicate cores reported by McDowell et al. Because core data of this type from other parts of the Everglades were not available, we assumed that the relative rate of peat accretion was the same as that found in the Belle Glade sample by McDowell et al. Therefore, if the core indicates that roughly half the thickness was formed in 3,000 years, we assume that is true whether the final peat thickness is 12 feet or 2 feet. We would calculate that the first area would have accreted 6 feet of peat and the second area 1 foot. This uniform peat accretion rate assumption was necessitated by the paucity of data, rather than by evidence that relative rates of peat accumulation were similar in different regions. Fortunately, the potential inaccuracy of this assumption does not diminish our ability to make qualitative judgments on how the system developed. Using this approach and the bedrock elevations in the Everglades region (shown in Figure 4), we reconstructed the formation of the peat deposits that underlie the Everglades. The peat surface elevation was obtained by adding the calculated peat thickness to the bedrock elevation. Calculated peat elevations for 1,000, 2,000, 3,000 and 4,000 years before the present time are shown in Figures 8-11. These maps show how the topographic features of the bedrock were being gradually filled in by the peat deposits.

NSM simulations were run for each of the four topographic profiles using the 30-year rainfall input from 1965 to 1995. This input is currently being used by the SFWMD to model flows in the pre-drainage Everglades. Sea-level change over the 4,000 year period (Fairbridge, 1974, reproduced in Figure 12) was also incorporated as a modified boundary condition. The current boundary of Lake Okeechobee was represented as a set of marsh cells to account for the variable boundary of the lake over the extended time period of these simulations.

Key results of the modeling are shown in Figures 13-16. The model grid and selected transects across which flow was calculated are shown in Figure 13. Three transects each in the southern and eastern directions south of Lake Okeechobee were used.

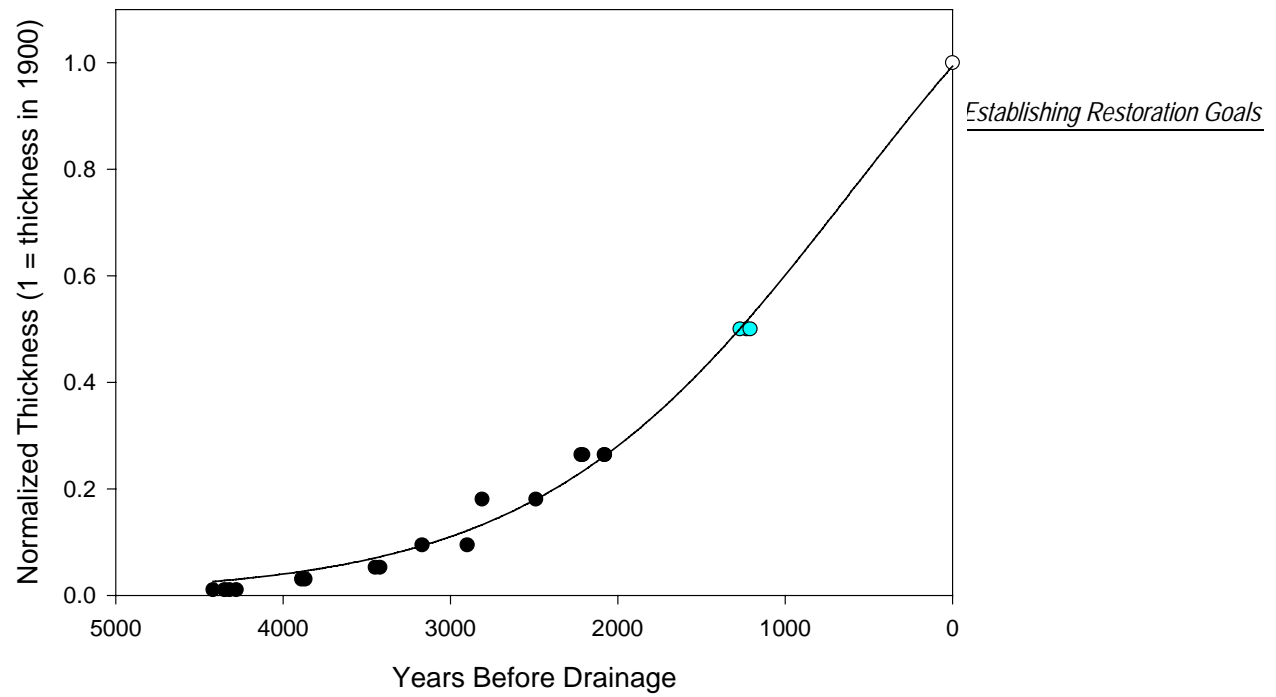


Figure 7. Peat core depth and age as obtained by carbon-14 dating at Belle Glade, Florida. These data are from McDowell et al. (1969). Data represented by the blue circles have been corrected for subsidence by the McDowell et al. The open circle represents the projected top of the peat deposit prior to drainage.

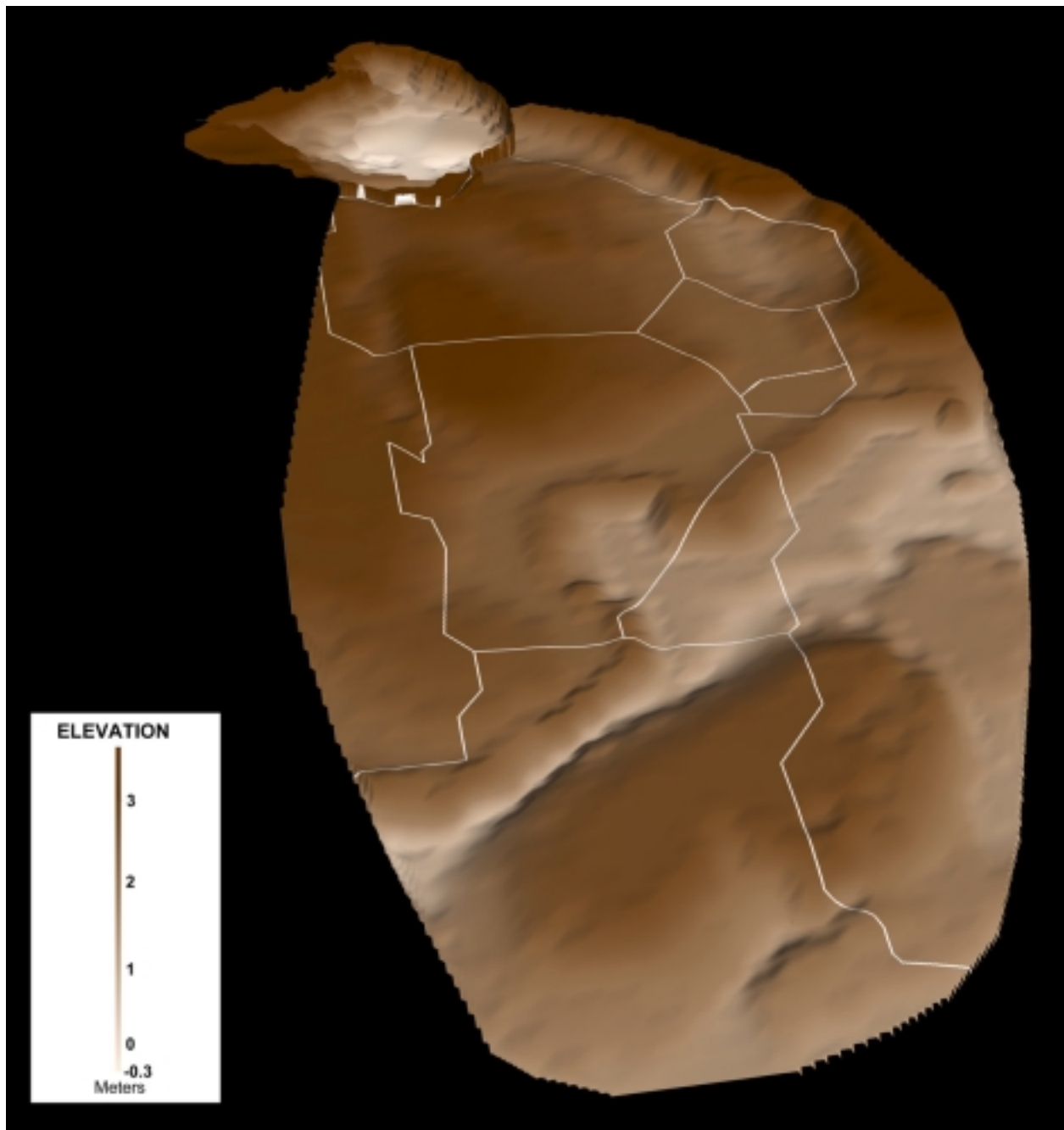


Figure 8. Projected elevations of the Everglades region 4,000 years before the initiation of drainage. These elevations were reconstructed from peat core dating.

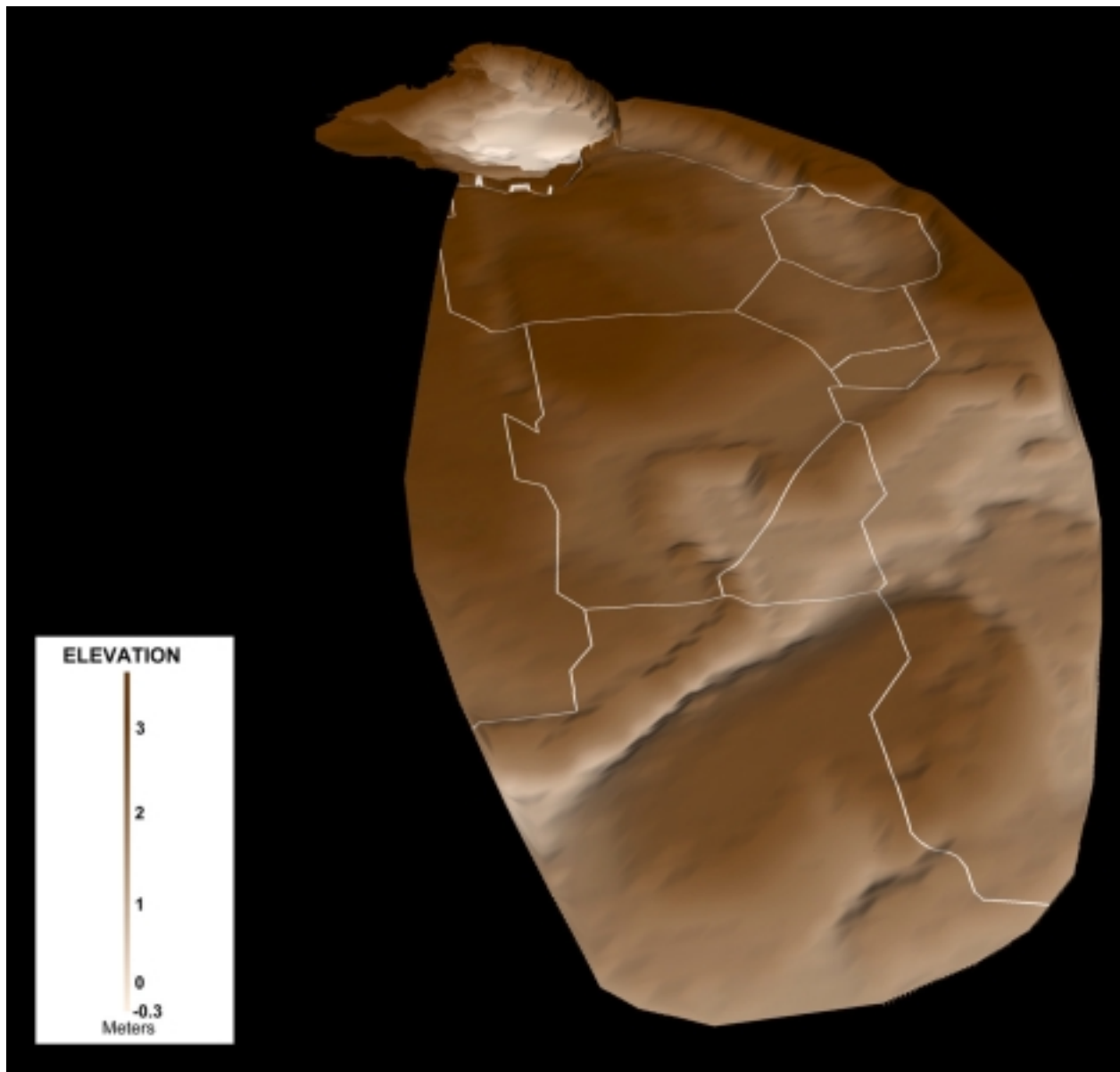


Figure 9. Projected elevations of the Everglades region 3,000 years before the initiation of drainage. These elevations were reconstructed from peat core dating.

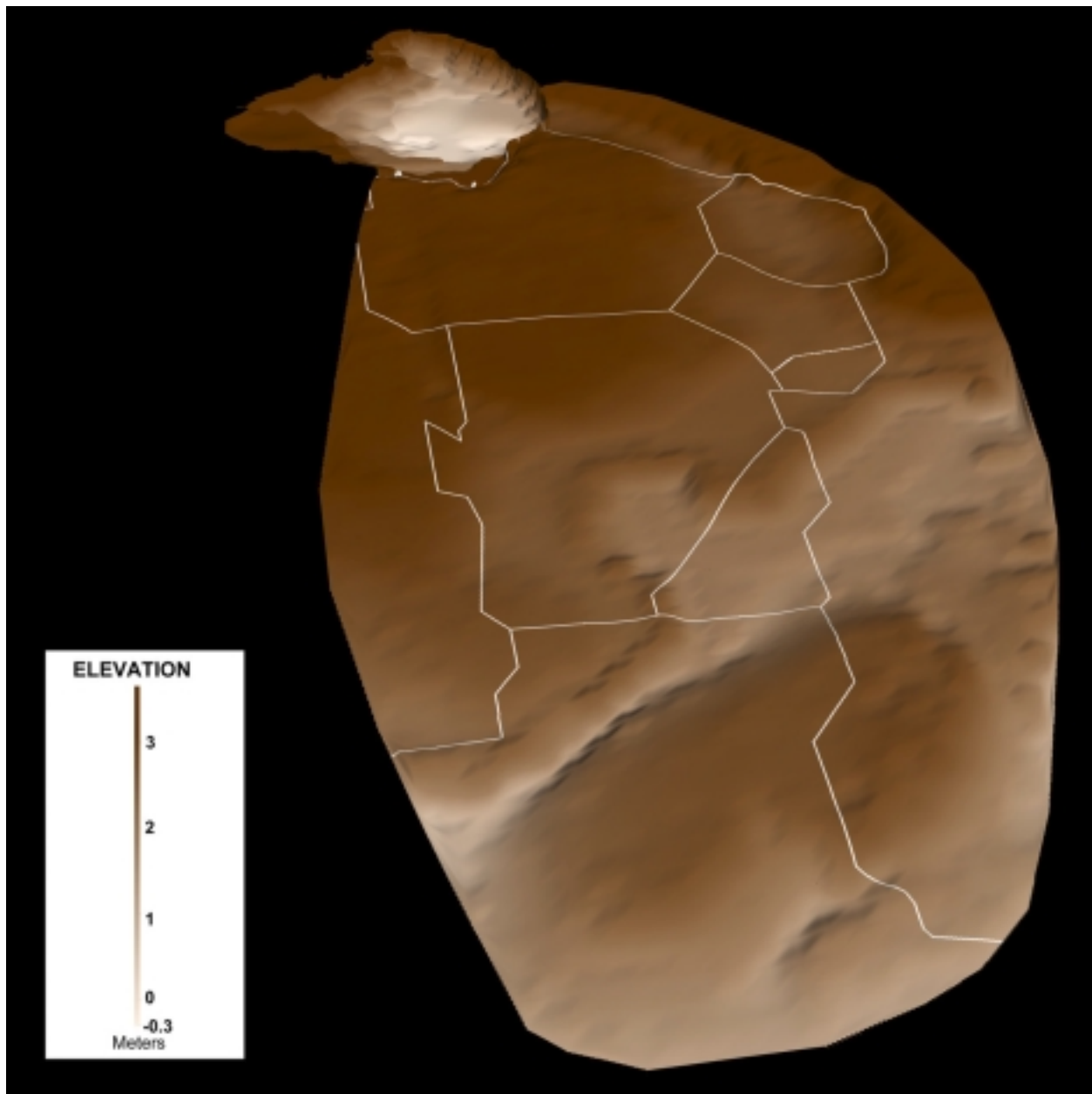


Figure 10. Projected elevations of the Everglades region 2,000 years before the initiation of drainage. These elevations were reconstructed from peat core dating.

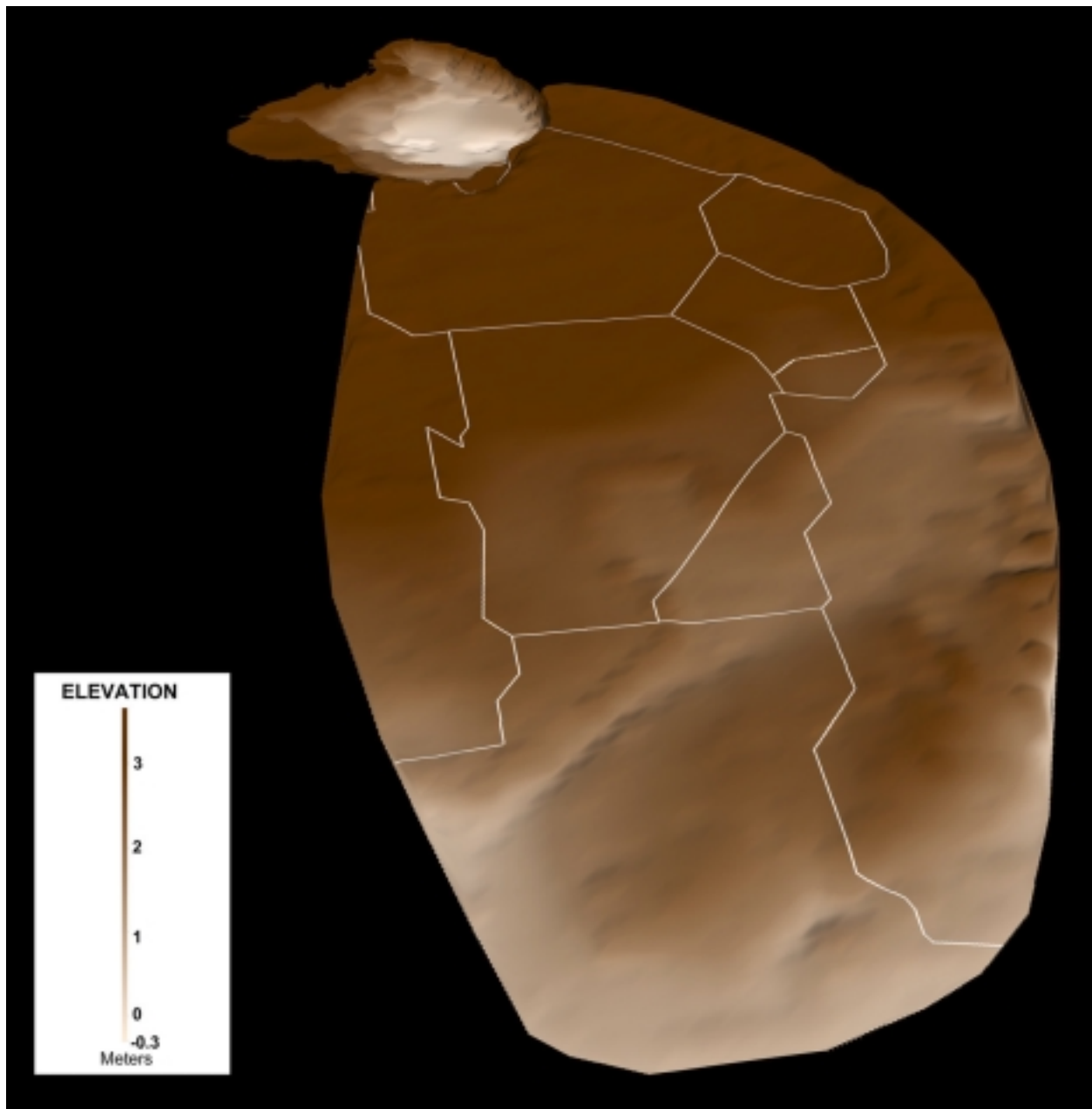


Figure 11. Projected elevations of the Everglades region 1,000 years before the initiation of drainage. These elevations were reconstructed from peat core dating.

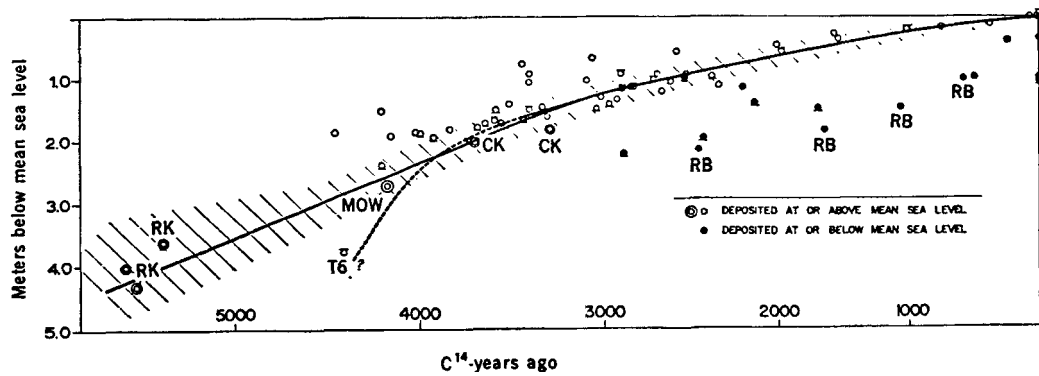


Figure 12. Sea level change in south Florida over the past 5000 years. The letter codes on the plot indicate different core locations, and the solid line represents the average sea level curve for Florida. This figure was reproduced from Fairbridge (1974).

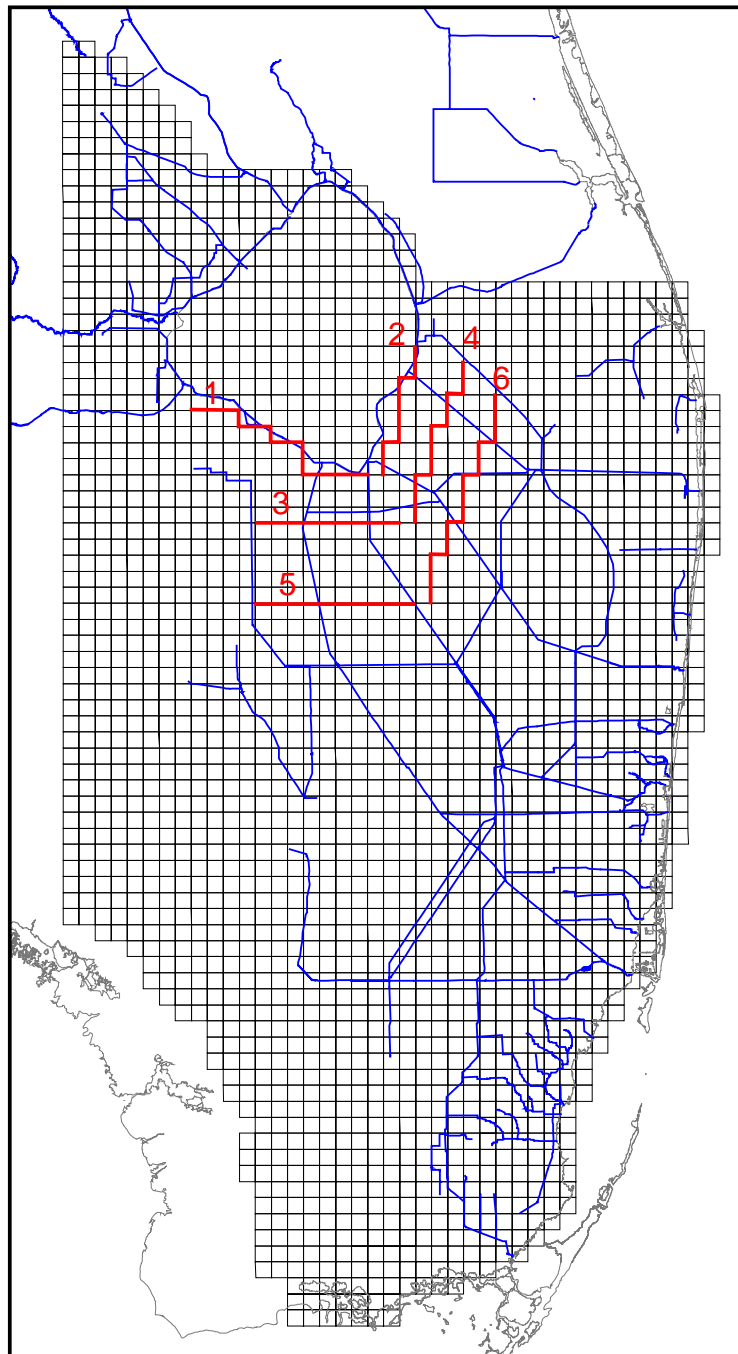


Figure 13. NSM model grid with selected transects where average flow values were calculated.

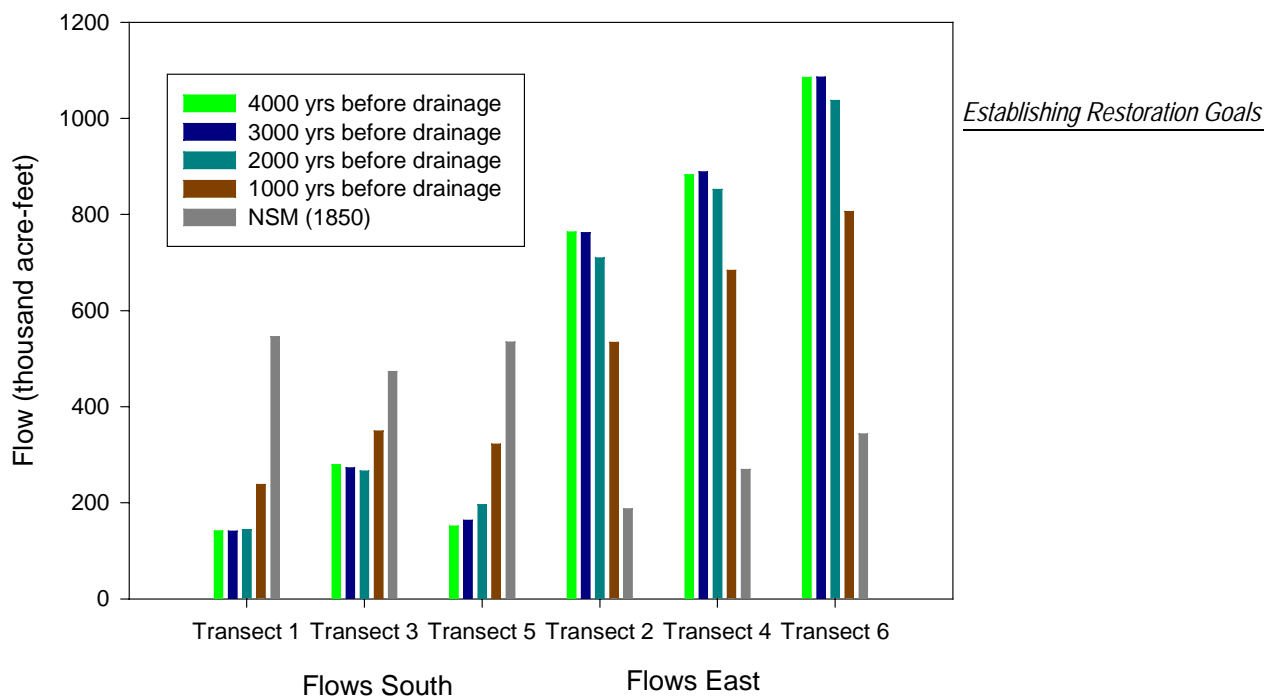


Figure 14. Calculated flows at the different transects identified in Figure 13 for topographic data from 1000, 2000, 3000, 4000 years before the base case year, and for the NSM base case year (1850).

Depths in Lake Okeechobee

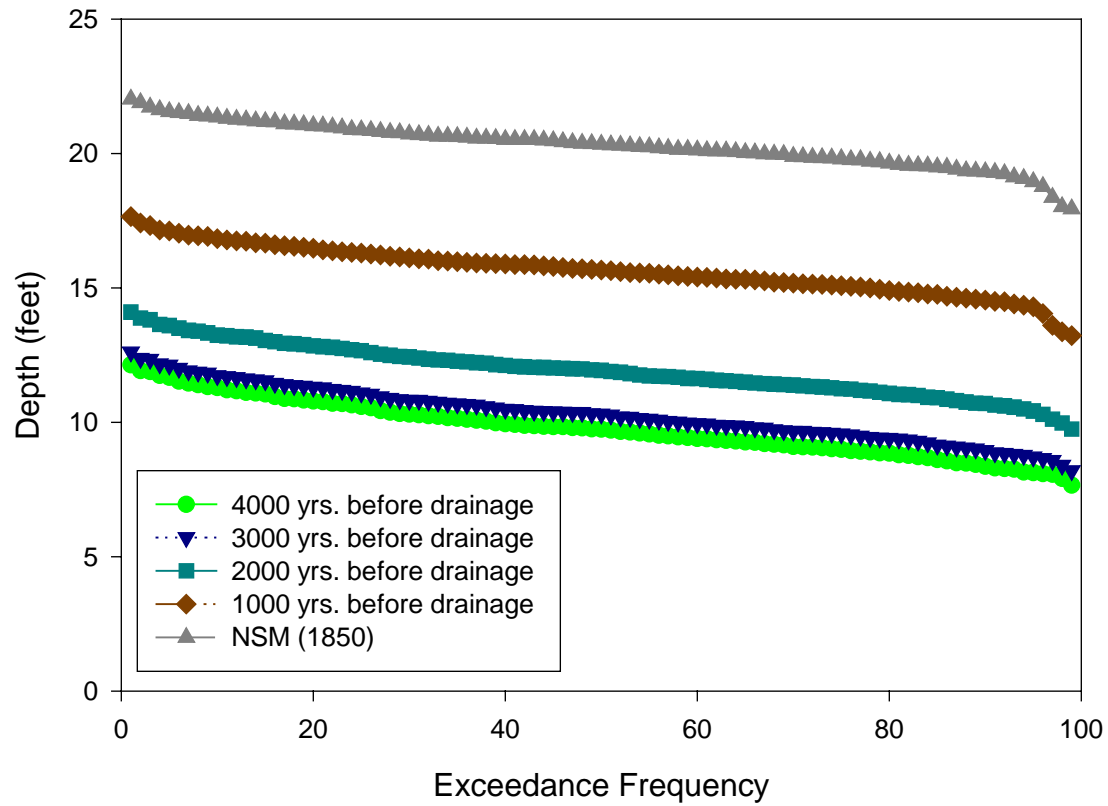


Figure 15. Water depth frequency calculated at the middle of Lake Okeechobee for the NSM base case and for topographic profiles representing 1,000, 2,000, 3,000, and 4,000 years before drainage.

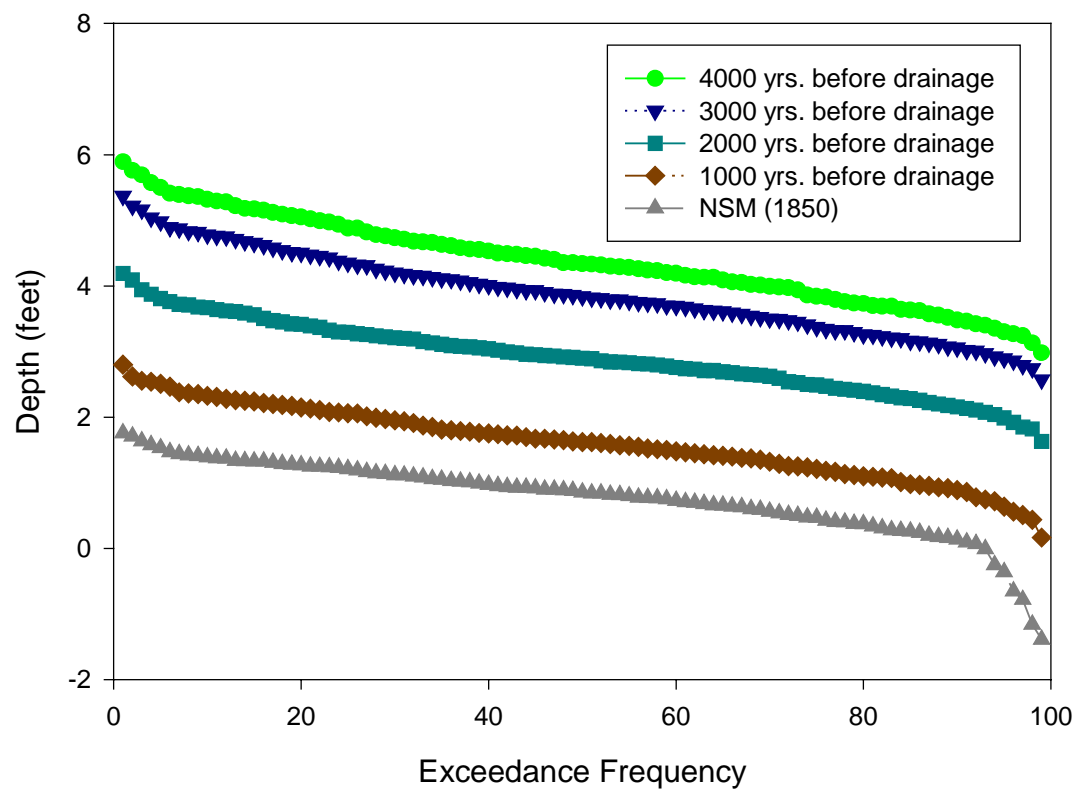


Figure 16. Water depth frequency in the middle of the current boundaries of WCA-1 for the NSM base case and for topographic profiles representing 1,000, 2,000, 3,000, and 4,000 years before drainage.

The average flow across these six transects is shown in Figure 14 for the NSM base case year, and for topography corresponding to 1,000, 2,000, 3,000, and 4,000 years prior to drainage. As we earlier described qualitatively, this figure shows that in the early years of this ecosystem, there was far greater flow to the east (transects 2, 4, and 6) of the lake than directly south (transects 1, 3, and 5). Over the years, as the areas on the east were filled in by peat deposits, flow directly south of the lake became the preferred pathway.

The depth of water in the area over WCA-1 was historically more similar to the depth of water in Lake Okeechobee than when European explorers first explored the region. The water depth frequency, that is, the percentage of time the water was above a given depth, is shown for a location in the middle of the current boundary of Lake Okeechobee for the NSM base case (the year 1850) and for the four preceding periods discussed (Figure 15). These results indicate that water depth in the lake increased over time. The water depth frequency for a location in the middle of the current boundaries of WCA-1 is shown in Figure 16. The historical depths are shown to be consistently greater than the NSM base case year (1850), sometimes as much as 3 feet deeper on average. One can surmise from this result that the WCA-1 area functioned more like a lake than a marsh.

This conclusion is also confirmed by the basal peat ages, that is, a wide band of land parallel to the Loxahatchee channel in the bedrock (Figure 4) was effectively the shoreline of a larger lake, and formed at roughly the same time. Because Lake Okeechobee was naturally higher in nutrients, as discussed in greater detail below, phosphorus-rich deposits probably extended over a much wider area than is currently understood. This finding is vital to the ongoing restoration efforts in the Everglades.

Vegetation

The pre-drainage vegetation of the Everglades has been described in several surveys conducted in the latter part of the 19th century and the early 20th century (Ober, 1887; Heilprin, 1887; Small, 1918; and summaries of various historical documents by McCally, 1999, and Hall, 2000). These reports refer to the presence of a dense forest that included pond apple (or custard apple, *Annona glabra*) south of the lake shore. Other species of trees were also present in this area, but for brevity, we will refer to this zone as the “pond apple” or “custard apple” zone. These trees were almost 30 feet tall and contained many other types of epiphytic vegetation, principally vines, ferns, and orchids, in their understory. The widespread occurrence of epiphytic vegetation, such as orchids and bromeliads, has been documented in recent studies of pond apple communities in Panama (Zotz et al., 1999). The forested zone was lost shortly after development began in the Everglades and appears to have been almost

completely lost by 1940, as shown in the aerial photographs from that time (Figure 17). These composite photographs clearly show agricultural development in a narrow band along the shores of Lake Okeechobee, which was identified as the location of the pond apple forest by Davis (1943).

Vegetation further south of the lake has been described in great detail by Davis (1943). Davis' map has been reproduced in Figure 18. The pond apple vegetation transitioned to elderberry and to dense sawgrass south of the lake. The sawgrass in this zone reached heights of twelve feet and presented a near-impenetrable barrier to explorers (Ober, 1887; McCally, 1999; Baldwin and Hawker, 1915). The sawgrass zone extended for several miles and gradually changed into a community with open water and less-dense sawgrass ending in the mangrove zone at the southern end of the Florida peninsula. Interspersed in this landscape were tree islands, essentially regions of slightly greater elevation that contained an abundance of trees and shrubs. The vegetation on tree islands was distinct from the surrounding marsh and was a vital component of the ecosystem. Altogether, this landscape provided greater diversity of vegetation, than is conveyed by the "river of grass" metaphor (McCally, 1999).

It has been argued, based on an examination of the sediments south of the lake, that the custard apple zone is fairly recent (Dachnowski-Stokes, 1930 quoted in Gleason et al., 1974). However, the lack of custard apple materials in the sediment is not found to be surprising by McCally (1999) because of the relative softness of the wood of this tree and also of the fact that the location of the zone may have varied with the boundary of the lake. McCally (1999) writes:

"The extensive deposits of peaty soils that underlie much of the southern expanse of Lake Okeechobee indicate a dynamic lakeshore whose location has fluctuated widely during the some five thousand years of peat formation. That is, as the lakeshore moved, so did the custard apple belt. Stated another way, the custard apple belt represents a biotic association rather than a particular location, and the location of that association has presumably always been along the southern shore of Lake Okeechobee."

Soils

The soils south of the lake were naturally highly enriched in phosphorus. Soil phosphorus measurements by Hammar (1929) indicate that samples collected within a few miles of the Lake Okeechobee shoreline contained phosphorus levels similar to those now seen in the most nutrient enriched parts of WCA-2A (Figure 19). Soil

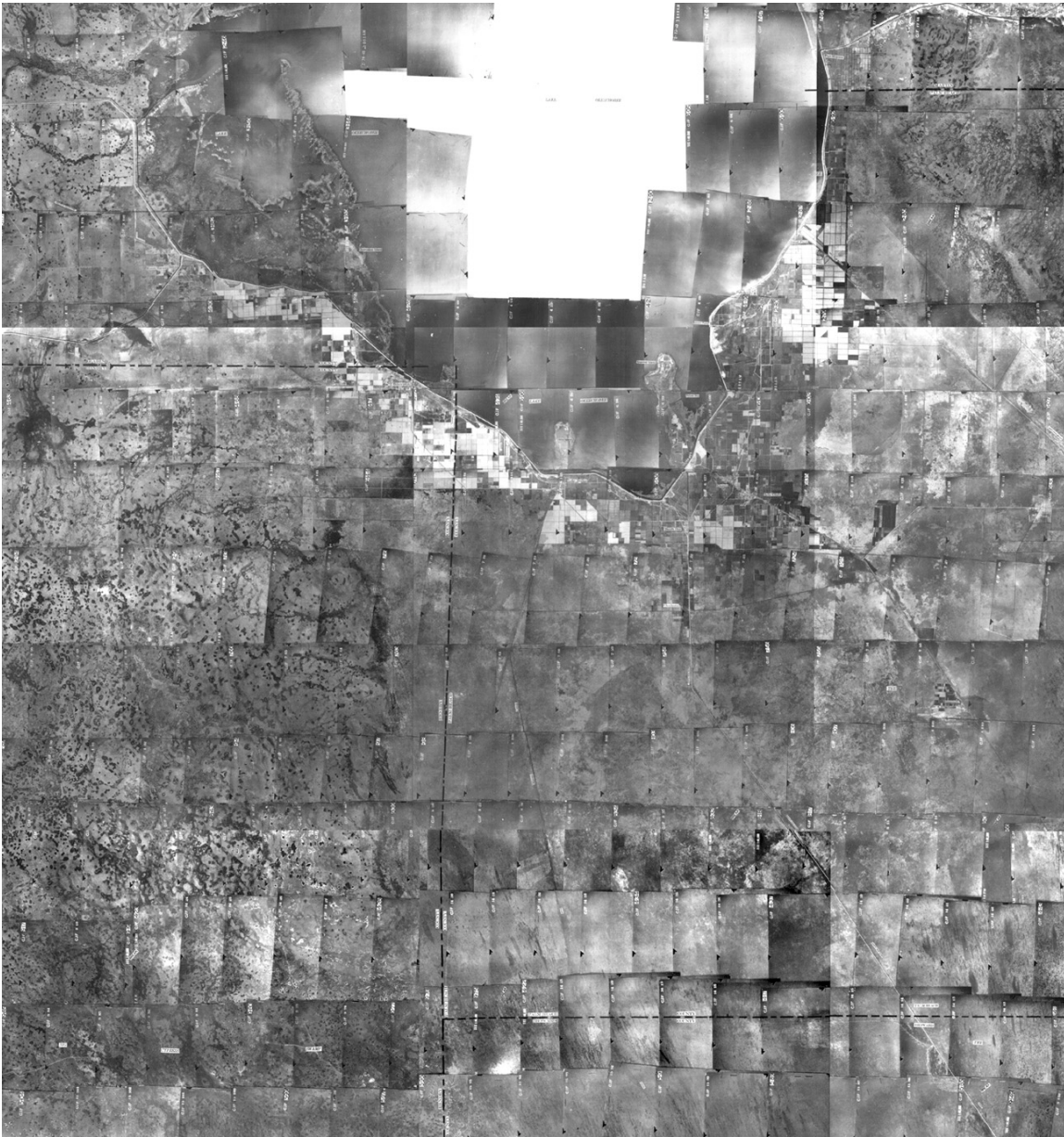


Figure 17. Aerial photographs of the area south of Lake Okeechobee taken in 1940. Individual photographs were composited by the U.S. Department of Agriculture and were obtained from the National Archives, Washington, DC. These photographs show that at this time agricultural development was confined to a narrow band along the south shore of Lake Okeechobee, and much of the current EAA was not cultivated.

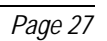


Figure 18. Vegetation of South Florida as recorded by Davis, 1943.

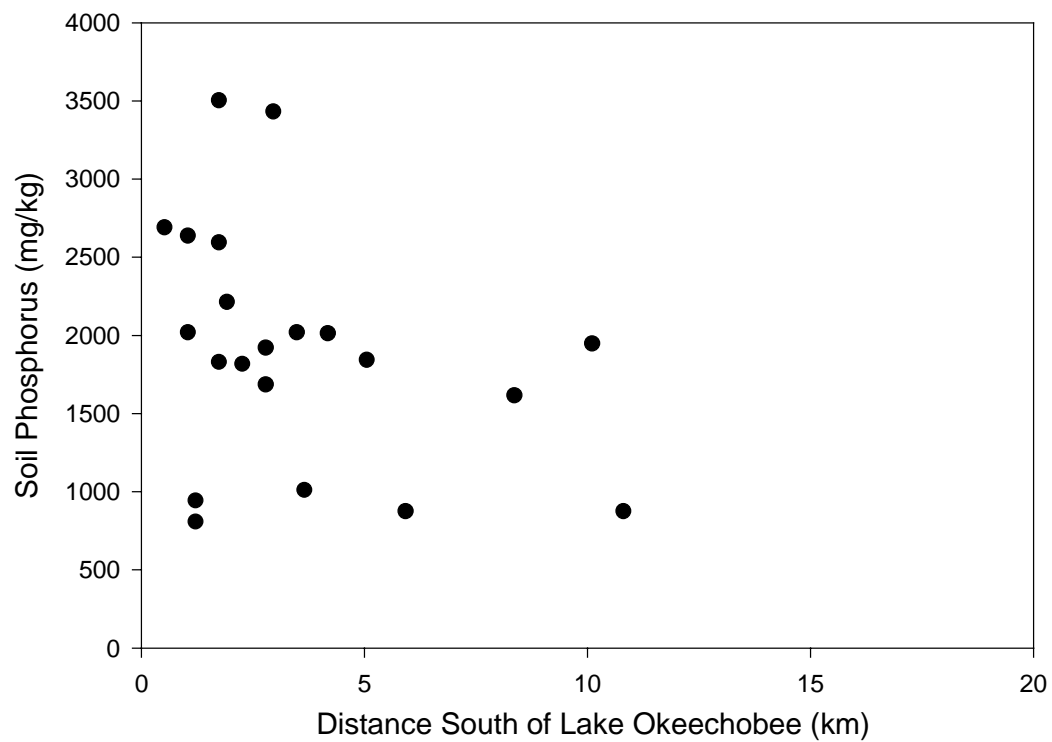


Figure 19. Phosphorus in soils as a function of distance from the shoreline of Lake Okeechobee as reported by Hammar (1929). A map in the original reference was used to calculate the distance of individual points from the Lake Okeechobee shoreline.

surveys along the Hillsboro, North New River, and Miami Canals in 1912 (Rose, 1912) also show a gradient of soil phosphorus, with higher concentrations near the lake and decreasing concentrations away from the lake. The presence of high phosphorus is in agreement with observations of natural zones of high phosphorus in the soils and sediments of this region. Wiley (1891), for example, reported the presence of pure pebbles of phosphate minerals in the marl underlying Okeechobee muck. Although the specific source of phosphorus in Lake Okeechobee water is not known, the presence of extensive phosphatic deposits in the region north of Lake Okeechobee may play a role. In developing reference nutrient levels of lakes in general, the US EPA emphasizes the role of the geology of the surrounding landscape (US EPA, 1999); sedimentary rocks, that underlie much of South Florida, are known to leach higher levels of nutrients than other types of bedrock.

Phosphorus levels in the peat soils of the Everglades are also correlated with peat thickness. The areas of high soil phosphorus also had the thickest deposits of peat. Because peat forms from the remains of decaying vegetation, and vegetation grows most densely where nutrients are available, it is not surprising that peat thickness and nutrient concentrations are positively correlated.

In areas of the remaining Everglades away from the inflow structures, and with the exception of a few localized high points and tree-islands, soil phosphorus concentrations in the upper 30 cm are fairly low. We have earlier hypothesized the existence of a nutrient-enriched zone along the edges of a larger Lake Okeechobee. Why do these enriched zones not appear in soil surveys performed within the current boundaries of WCA-1 (USEPA, 1998)? It is our belief that the initial deposits were enriched, but as the “lake” gradually became a marsh, the flows lost their phosphorus to algae and plant uptake by the time they reached the Loxahatchee area. Thus, it is conceivable that the enriched deposits were overlain by deposits relatively low in phosphorus, and that measurements of the upper layers of peat do not reflect the historical enrichment. A study of phosphorus in the deepest layers of peat in these areas has not been reported, to our knowledge. Paleo-ecological techniques may provide additional insight into the development of these peat deposits.

It has been argued for portions of the remaining Everglades where phosphorus was introduced into the system by anthropogenic sources, that a “moving front,” i.e., a zone of high concentration will continuously move deeper into the marsh until the entire marsh is saturated with phosphorus. However, the same processes led to the natural formation of the peat deposits of the northern Everglades, where a phosphorus enriched source flowed into the marsh for centuries without expanding into the phosphorus-poor southern Everglades. The phosphorus that entered the ecosystem

was incorporated as deeper peat rather than higher downstream concentrations. This process is occurring at a smaller spatial and temporal scale in the northern part of WCA-2A, where phosphorus-enriched water has caused enrichment of peat phosphorus near the source, although concentrations in the interior of the marsh are generally lower and stable. The additional phosphorus leads to higher biomass and higher accretion rates of peat (Craft and Richardson, 1993) but not a continuously moving front. This is confirmed by frequent measurements of soil phosphorus in the upper 10-cm from 1990-1997 (summarized by Tetra Tech, 1998). The historical presence of a high phosphorus zone in peat that has likely existed for many centuries without marching into the southern Everglades further demonstrates the fallacy of the moving front argument.

Nutrients in Lake Okeechobee

Based on phosphorus concentrations in Lake Okeechobee sediment cores (Brezonik and Engstrom, 1997), it is generally believed that although phosphorus concentrations have increased in recent years, the lake was enriched in phosphorus prior to the development of its drainage basin in the 20th century.

In addition to sediment core data, the earliest historical reports describe a density of vegetation in and around the Lake Okeechobee area that would not have been possible in the absence of adequate levels of nutrients. For example, a report from an 1841 topographical examination of Lake Okeechobee and the inflowing streams (as documented in Sprague, 1848) found dense vegetation in the southwestern region of the lake that prevented passage into the lake on canoes. It also appears that algae blooms were at least an occasional feature of the lake. During an extensive exploration of Lake Okeechobee, Ober (1887) writes that “The water of the lake is so thick with organic matter that we could not drink it unless boiled with coffee.” He later describes the experience of arriving at a clear pool of water in the marshes after they had completed their exploration of Lake Okeechobee: “From this pool we dipped up water clear and sweet. Oh, how refreshing to our parched lips, after two weeks of the green broth of the lake!” Heilprin (1887) visiting the lake at roughly the same time wrote that although the lake was reported to be a “vast, swampy lagoon” he found the water clear. Small (1918) reports the presence of water lettuce and water hyacinth in the southern part of Lake Okeechobee in 1913, which would also indicate relatively high nutrient levels.

The concept of lakes being impaired in their function as a result of elevated nutrient concentrations is largely based on studies of northern lakes. Discussion of Lake Okeechobee phosphorus concentrations in this context may lead to the incorrect conclusion that higher productivity is inherently harmful (Canfield and Hoyer, 1988).

For example, the phosphorus goal in the lake has recently been set at 40 ppb in the TMDL process, based on the occurrence of algal blooms at concentrations higher than this level. But such blooms may not have been uncommon in the natural system as indicated by the historical reports quoted above.

An important ramification of the lake being at a higher concentration than the oligotrophic areas of the southern Everglades is that there must historically have been a transition zone from intermediate to low concentrations of phosphorus. Although the historical water concentrations of Lake Okeechobee are not known with any precision, a similar gradient of phosphorus concentrations exists in the Everglades today where phosphorus-containing runoff is introduced into the Water Conservation Areas and will occur to some extent with the existing and planned STAs.

Wildlife

Lake Okeechobee in general, and the forested areas in particular, were reported to be home to a large number of birds, mammals and amphibians by 19th century hunters and explorers (Ober, 1887, Heilprin, 1887). For example, Ober (1887) reported that, on Observation Island in Lake Okeechobee, “the great white heron had nests on every tree” and that the “dark masses of ipomea were dotted with herons.” The south shore of Lake Okeechobee was lined with “reeds, canes, and scrubby willows, and the successive points terminate in scraggy “custard apple” trees, filled with the nests of cormorants and snake-birds.” Alligators and snakes were also reported to be abundant.

Small (1918), describing a cruise made in 1913, refers to birds in Pelican Bay area of Lake Okeechobee: “It was surrounded by beautiful pond apple hammocks which were fringed with a growth of water hyacinth and water lettuce made up of plants more robust and larger than had previously been recorded. The hammock islands served as immense heron rookeries and the waters abounded in alligators of all sizes.”

In contrast to the abundant wildlife in the forested areas, sawgrass marshes had very few birds and fishes (McCally, 1999 quoting from the report of the 1883 Times-Democrat expedition to the Everglades). The expedition report compared the shores of Lake Okeechobee with large numbers of alligators to the sawgrass marshes where a “deathlike oppressive stillness prevailed.” These sawgrass regions were said to be “devoid of game” and “there were no fish in the water, no birds in the air.”

2. IMPLICATIONS FOR RESTORATION

In ongoing work by the Florida Department of Environmental Protection to develop a numeric threshold for water column phosphorus in the Everglades, the approach used has been to study conditions that occur at reference stations, and to define imbalance in terms of deviations from the reference conditions (FDEP, 1999). All reference stations selected have been in the oligotrophic areas of the Everglades. Because the natural zones of higher phosphorus have been almost completely lost, no reference stations represent conditions of higher phosphorus concentrations such as the swamp-forest zone, which included the pond apple forest and covered 178,000 acres in the historical system (US Department of Interior, 1997)¹. Also, tree island areas, which were widespread in the original landscape and are known to have higher phosphorus concentrations, now appear in greatly diminished numbers and area. Tree islands are not represented at all in the reference stations.

An interesting comparison of historical and recent conditions (such as those that might result after the EFA implementation) can be made based on the distribution of water column phosphorus concentrations in the original and the remaining Everglades. This can be done using model calculations of the natural and the current system following the implementation of EFA restoration components. Calculations for the natural system were made using flows from the NSM and a mass balance model of phosphorus uptake and settling (Walker and Kadlec, 1996). Calculations for the current system were made using the Everglades Phosphorus and Hydrology Model (Munson et al, 1999), a tool specifically developed to understand phosphorus transport in the remaining Everglades.

Historical areas of different levels of water column phosphorus were estimated using the following approach: flow of water from Lake Okeechobee through the forested zone at the lake rim was assumed to occur without any reduction in phosphorus concentrations; starting at the downstream edge of the forested zone, phosphorus concentrations were assumed to decrease with distance using the Walker-Kadlec (1996) model of phosphorus transport. There are two reasons why we assumed that water flowed through the forested zone without diminution. First, this zone was home to large bird populations that are known to provide significant nutrient inputs through their droppings (Baxter et al., 1994; Scherer et al., 1995; Post et al., 1998). Second, the soil phosphorus concentrations measured in 1929 in the areas south of the lake (shown in Figure 19) do not indicate a reduction in the first five miles from the lake edge. Because soil concentrations reflect the concentrations in overlying water,

¹ The source of these data are not provided in the original report. We have digitized the Davis (1943) map and found that the area represented by the pond apple and elderberry zones south of the lake represents about 139,000 acres. It is possible that forests in other zones were included to develop the 178,000 acre estimate.

this would indicate that there was no significant decrease in phosphorus concentration in water in the first five miles from the lake edge. The Walker-Kadlec (1996) model of phosphorus transport in Everglades marshes was applied at the edge of the swamp forest zone using inflowing water concentrations at 30 or 50 ppb of phosphorus, and using flows across the edge of the forested zone calculated from the NSM. The settling rate was half of that currently measured in WCA-2A, based on the knowledge of significantly slower peat accretion historically than in modern times (McDowell, 1969 and Craft and Richardson, 1993, 1998)². Calculations from the Walker-Kadlec model showed that the marsh area greater than 10 ppb in the pre-drainage Everglades would be roughly 146,000 acres at 50 ppb input and 118,000 acres at 30 ppb input. Added to the forested zone calculated from the Davis (1943) map (139,000 acres), this would represent an estimated total of between 257,000 and 285,000 acres containing more than 10 ppb of phosphorus in the pre-development ecosystem.

To represent modern conditions, following EFA implementation with STAs discharging at 50 ppb, areas of different phosphorus concentrations were obtained from runs of the Everglades Phosphorus and Hydrology (EPH) Model (Munson et al., 1999) which represents the remaining portions of the Everglades. The EPH model showed that, after EFA implementation, the area over 10 ppb will occupy roughly 230,000 acres. This can be compared with the 257,000 to 285,000 acre estimate obtained for the historical system. Because the total area of the wetland changed from approximately 3 million acres before development to 1.5 million acres currently (US Department of Interior, 1997), the areas greater than 10 ppb in the modern system will be a larger percentage of the total wetland area than in the past, but should be acceptable given the significance of this habitat to higher trophic levels.

The numeric threshold for phosphorus that is calculated using the FDEP reference station approach, not surprisingly, is a very low concentration that occurs in the oligotrophic areas of the marsh. Should restoration continue along this path, the process will force the remaining system to a type of habitat that we know was only a part of the Everglades, and the least productive habitat at that. In this case, it is possible that this approach will eventually lead to the creation of a sawgrass-slough area a few percent greater than currently remains in the ecosystem. While it is true that over many years this may return the current nutrient enriched areas to the type of vegetation they historically contained (e.g., as shown in the map by Davis, 1943), this

² Average annual flow across transects just beyond the forested zone was obtained from NSM runs and was 742 thousand ac-ft per year and the combined transect width was 70 km. Using a peat thickness of 12 feet south of Lake Okeechobee, the peat accretion rate estimated in the last 1000 years from Figure 7 was ~2 mm per year. This compares with an accretion rate of 4 mm per year (Craft and Richardson, 1993) in nutrient enriched zone of WCA-2A where the settling rate was calculated to be 10.2 m/yr (Walker and Kadler, 1996). We therefore used half this settling rate (5.1 m/yr) for calculating the long-term water column phosphorus gradient in the Everglades.

simplistic restoration target would not be faithful to the diversity of habitats that existed in the entire Everglades or that supported the wildlife populations that are the ultimate goal of restoration. The existence of a natural gradient of phosphorus concentrations is not represented anywhere in this restoration plan.

The restoration approach must include the presence of different habitats that have been totally lost in the current system but whose functionality may be re-established. When one considers the existence of enriched areas, and their role of providing a distinct ecological habitat that was vital to birds and other wildlife, which are highly valued components of the ecosystem, specific efforts to include these habitats in restoration goals must be made. These efforts could include planting of vegetation that was found in the pond-apple zone and/or the vegetation that is commonly found in tree islands and improvement of hydroperiod.

The areas downstream of the STAs and nutrient-enriched area in the northern part of the WCA-2A appear to be suitable locations for supporting these other habitats. These areas will have an additional supply of nutrients at water concentrations that are comparable to what the pre-development Lake Okeechobee provided to the northern Everglades, which was important historically in the area south of lake. In addition, because of the higher nutrient supply these regions are also likely to experience relatively rapid accretion of peat (based on research from WCA-2A by Craft and Richardson, 1993) and, because of the higher resulting elevation, will increasingly favor the growth of tree island vegetation. Some species of tree island vegetation are now found growing in the enriched areas of WCA-2A. Enhanced peat accretion in areas downstream of the STAs is a desired objective of ecological restoration planned as part of the Restudy (FWS, 1999). Also, the northern part of WCA-2A has been described as “an extremely valuable wading bird habitat” by Hoffman et al., 1994. They write that “It is the single unit most used by wood storks and often hosts great numbers of white ibises. Glossy ibises also use it extensively. It also appears very important to tri-colored herons.” We have also shown, using peat core radiocarbon data and historical topographic profiles that a historical nutrient-enriched zone may have extended as far south as the northern tip of WCA-2A. The location of the new enriched zones in these areas would not be outside the range of dynamics exhibited by this ecosystem in the previous 4000 years.

The conditions that fostered the unique growth of the pond apple forest near the shores of the lake may have had to do with the presence of slightly higher mineral contents in the soils of this region, the presence of water all year round, the absence of frost because of the tempering effect of the lake, and the greater availability of nutrients. The first three of these conditions may be absent in other parts of the

Everglades and the successful growth of pond apples in these areas should be tested. The enriched portion of WCA-2A may be a good growth site. Should pond apple vegetation not grow well in the WCAs, the use of tree island vegetation could be considered.

This thesis is consistent with the widely used approach developed by the U.S. Fish and Wildlife Service to evaluate the loss of habitat (FWS, 1980). The Habitat Evaluation Procedures (HEP) guidelines involve assessing the suitability of each type of habitat when natural areas are lost to development. Species are assessed for their abundance, vulnerability, replaceability, aesthetic value, and the management efforts needed to sustain their populations. Likewise, habitats are assessed for their suitability to different species. In calculating the loss of habitat, weight is given both to the importance of the species on the above criteria and the result of habitat loss on the different species. The goal is to minimize the habitat loss of the most valuable species. Using such a concept, it may be argued that trees in the Everglades, whether part of the pond apple forest or tree-islands, are more valuable than sawgrass marshes because they are known to be home to greater populations of birds and wildlife, and should therefore be actively considered for restoration. A quote from McCally (1999) pertains directly to this issue:

“The major flaw of the river-of-grass metaphor is the way the figure of speech distorts the truth about animal habitat in the Everglades. While traveling through the interior marsh, members of the Times-Democrat expedition encountered a rich mosaic of dense saw grass stands, abundant flag marsh, and numerous tree islands, but very few animals. The most desolate areas of all were those where saw grass dominated...By contrast, Williams reported, the mangrove forest along the Shark River, like the forested shore of Lake Okeechobee, provided nesting sites for a vast rookery of “thousands of birds.”...Modern Floridians must be aware that the current myopic focus on sawgrass will not lead to anything like an environmental restoration of south Florida; rather, the creation of vast stands of sawgrass will bequeath modern Florida the same sterile environment that Archie Williams encountered in 1883.”

Utilization of the areas downstream of the STAs and northern WCA-2A to develop some of the ecological niches that have been lost can lead to a restoration that comes closer to providing the heterogeneity of habitats that was vital to the historical Everglades. A nutrient enriched habitat, even if it is relatively small, may be more valuable to birds and wildlife, and to the public perception of the health of this ecosystem, than the corresponding addition of sawgrass marsh, which is already extremely abundant in the Everglades.

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